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# Image Gathering, Coding, and Processing: End-to-End Optimization for Efficient and Robust Acquisition of Visual Information

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We are concerned with the end-to-end performance of image gathering, coding, and processing. The applications range from high-resolution television to vision-based robotics, wherever the resolution, efficiency and robustness of visual information acquisition and processing are critical. For our presentation at this workshop, it is convenient to divide research activities into the following two overlapping areas:

1) The development of focal-plane processing techniques and technology to effectively combine image gathering with coding. The emphasis is on low-level vision processing akin to the retinal processing in human vision. Our approach includes the familiar Laplacian pyramid, the new intensity-dependent spatial summation, and parallel sensing/processing networks. Three-dimensional image gathering is attained by combining laser ranging with sensor-array imaging. This work is summarized in the following five abstracts by T. Cornsweet, G. Westrom, E. Kurrasch and R. Holben, R. Holben and G. Westrom, and D. Coon and A. Perera.

2) The rigorous extension of information theory and optimal filtering to visual information acquisition and processing. The goal is to provide a comprehensive methodology for quantitatively assessing the end-to-end performance of image gathering, coding, and processing. Information theory allows us to establish upper limits on the visual information which can be acquired within given constraints, and optimal filtering allows us to establish upper limits on the performance that can be attained for specific tasks, even if these tasks require adaptive or interactive processing. This work is summarized in the remainder of this abstract.

The performance of (digital) image-gathering systems is constrained by the spatial-frequency response of optical apertures, the sampling passband of photon-detection mechanisms, and the noise generated by photon detection and analog-to-digital conversion. Biophysical limitations have imposed similar constraints on natural vision. Visual information is inevitably lost in both image gathering and low-level vision by aliasing, blurring, and noise. It is therefore no longer permissible to assume sufficient sampling as Shannon and Wiener could do in their classical works, respectively, on communication theory and optimal filtering for time-varying signals. Nevertheless, the digital processing algorithms (for image restoration, edge enhancement, etc.) found in the currently prevailing literature assume sufficient sampling, whereas image-gathering systems are ordinarily designed to permit considerable insufficient sampling. This fundamental difference between assumption and reality has caused unnecessary limitations in the performance of digital image gathering, coding, and processing. It has also led to unreliable conclusions about the correct design of image-gathering systems for visual information processing (as opposed to image reconstruction without processing, e.g., commercial television) and about the actual performance of image-coding schemes for tasks which involve digital image processing.

Our analyses so far have shown that the combined process of image gathering and optimal processing can be treated as a communication channel if (and only if) the image-gathering degradations are correctly accounted for. Correctly restored images gain significantly in fidelity (similarity to target), resolution (minimum discernible detail), sharpness (contrast between large areas), and clarity (absence of visible artifacts). These improvements in visual quality are obtained solely by the correct end-to-end optimization without increase in either data transmission or processing. Similar improvements can also be made in the resolution and accuracy of edge detection. Furthermore, if we implement the edge enhancement with focal-plane processing by properly combining optical response with lateral inhibition, it is possible to reduce data processing and transmission requirements and to improve robustness to noise. These results have encouraged us to extend our analyses to various image-coding schemes and the associated image restoration and feature-extraction algorithms.